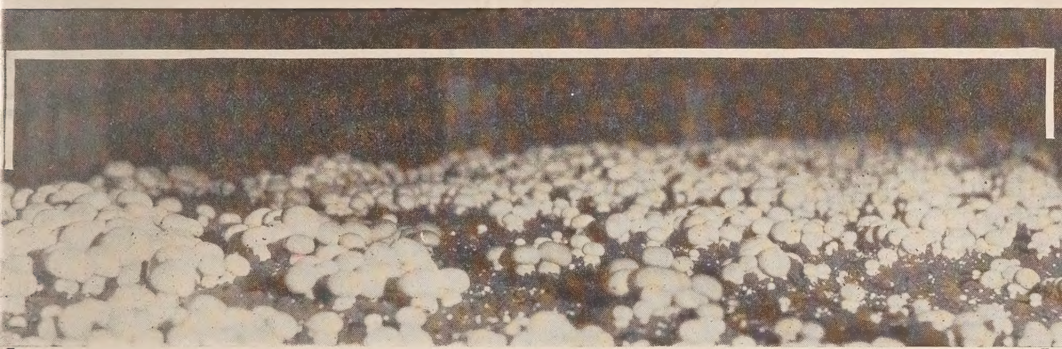

Synthetic Compost for Mushroom Growing

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Synthetic Compost for Mushroom Growing

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MUSHROOM growing in this country has, from the beginning, been dependent on the horse. The available supply of horse manure determines the location and volume of the business as much as market demand for the crop. In fact, the first investigation a prospective grower must make is into the source and adequacy of the manure supply. Unfortunately the supply cannot be certain even then. The rapidly dwindling number of horses, especially in city stables, has forced established growers to seek sources of poorer grade manure and at greater distances in order to maintain the present production level. This has increased the production cost because the price of the nearby supply of good manure has risen as competition for it has increased. There is, therefore, apprehension in the growers' minds concerning the future of their industry.

The obvious remedies for this situation are: first, more efficient use of horse manure; second, the use of other natural manures; and third, the development of a suitable synthetic compost or artificial manure. While all are important, the present report is concerned primarily with the last. It is not necessary at first that compost replace horse manure, but only that it supplement the supply sufficiently to keep the cost of the manure at a reasonable level. Probably a long transition period will occur while the synthetic material is being perfected and the natural manure supply is dwindling to insignificance.

For general agriculture, the use of organic fertilizer is considered good practice even though not absolutely necessary. The making and use of synthetic manure has been an object of investigation for many years. Since 1920, when the *ADCO* process was developed in England by Hutchinson and Richards *(5)*, many reports of its successful production and use have appeared. In this country the states reporting most of the experimental work are Missouri, Iowa, New York and Ohio. In general, the procedure follows that outlined by Hutchinson and Richards, the variations including omission or substitution of one or more ingredients, changes in concentration of ingredients, and minor differences in handling the ma-

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terial. All methods require several months to decompose the substance into compost similar to rotted manure. Straw is the basic substance. Ammonium sulphate and cyanamid are the usual nitrogenous ingredients added; ground limestone and superphosphate are the other ingredients. Water may or may not be added. There is no attempt to produce rapid and hot decomposition as this results in much greater loss of nitrogen.

ARTIFICIAL MANURE FOR MUSHROOM GROWING

General characteristics.—Composts made by a process such as the *ADCO* might be suitable for mushroom culture, but the length of time necessary for the production of such manure, its long exposure to rain and weathering, and the inadequacy of its thermogenic capacity appear to limit its usefulness for this purpose. The object in a mushroom compost is different from that sought in organic fertilizer for general farming. While manure which is to be distributed in the soil should add as large an amount of nitrogen, phosphate and potash as possible, the primary use of a mushroom compost is to supply abundant carbon compounds since the mushroom cannot manufacture these substances from carbon dioxide and water as do the green plants. Certain amounts of the inorganic elements must be present, but their concentration may be small compared with that of the carbon compounds since there is no dilution of them as when manure is applied to the soil. Loss of nitrogen in the composting process for mushroom growing is not, therefore, especially serious.

It is imperative, however, that the finished compost promote the growth of mushrooms to the exclusion of other fungi and bacteria. Decomposition at high temperatures apparently results in a compost with this desired quality. This is probably the result of a special succession of thermogenic and thermophillic micro-flora at the end of which the mushroom and a very limited number of other organisms become the dominant types. If this floral succession is disturbed or replaced by another, as it may be at lower temperatures, the mushroom may never be able to establish its dominance. Therefore, the type of artificial manure commonly made for general farming has never been considered to have value as a mushroom compost.

Review of previous research.—The first of previous studies on synthetic composts for mushroom growing was made by Hein *(2)* who used wheat straw as a base. To some piles he added various inorganic nitrogen salts, such as ammonium nitrate, ammonium phosphate and ammonium sulphate, and to others organic nitrogen, such as liquid manure, manure and garden soil. The time of composting was not reported. Yields varied so greatly that no definite

conclusion could be reached except that it is possible to grow mushrooms on straw with nitrogen added. Hein later *(3)* made composts of straw and soybean stover in varying proportion, but the yields were unsatisfactory.

Lambert, in 1931 *(6)*, reported much more favorable results from the use of dried blood, calurea and cyanamid as nitrogen sources. These were added on the basis of 10 to 20 pounds of nitrogen per ton of dry straw. The yields were more than 1 pound per square foot but were less than those obtained with horse manure alone. The temperature attained during composting, 120° F, was also lower than that of composting horse manure which is about 150° F.

More recently, Waksman and Reneger *(9)* reported on the production of synthetic compost consisting of straw in combination with tobacco stems and alfalfa. The temperatures of these piles equalled, and in some cases excelled, that reached by horse manure. After the materials had composted 44 days, a single mushroom bed was made from each material. Yields per square foot varied from 1 pound for the manure and for the straw mixture containing 30 per cent tobacco stems, to 0.1 pound when 40 per cent tobacco stems was used with 60 per cent straw. The alfalfa-straw mixture produced only 0.7 pound, but the spawn grew best in it. Chemical analyses at the beginning and at the end of the composting periods showed no differences which would account for the variations in yields.

In France, Demolon, Burgevin and Marcel *(1)* report that a combination of wheat or oat straw, gypsum, and urea composted 50 days and turned every 10 days, produced a good crop of mushrooms. Part of the urea could be replaced with potassium nitrate without decreasing the yield, but the addition of sulfate of ammonia reduced the crop materially. They conclude that to obtain good yields the pH should be below 8, the moisture content below 70 per cent and the organic constituents should be present in the following proportions per 100 parts dry weight: pentosans, 10 to 15; cellulose, 8 to 11; humic acid, 14 to 18.

Zangger *(10)* has patented a method using starch mixed with malt, dextrose, ammonium carbonate, potassium phosphate and calcium sulfate. No report of results with this mixture has come to the writer's attention.

In no case have the composts reported by these investigators been very satisfactory. All require a long composting period and the yields are so variable as to make their commercial use inadvisable. This has been perhaps because the investigators have, in general, sought a single formula or have used a certain substance in their attempts to develop a synthetic compost which would immediately answer the growers' needs.

Purpose of the experiments.—The series of experiments here reported had for its immediate object the determination of the effects of mixing ingredients in various concentrations and the economic limits of these variations, rather than the development of a formula which may be adopted for making synthetic compost commercially. The results indicate what ingredients may profitably be used in attempting to supplement the available manure, and the general proportions which may be expected to yield the best results.

We have always kept in mind the possibility of adapting agricultural waste products to mushroom growing. These may be derived from the farm directly, as weeds, straw and fodder, or indirectly as waste products from manufacturing industries, such as nicotine and licorice extraction and beer brewing. It was desirable, at first, to use materials available to all growers in unlimited amounts, thus giving an unbiased basis of comparison. Industrial wastes may eventually supplement the ingredients used in our experiments, especially in favored localities, with large savings to the fortunately situated growers and manufacturers. Each material, however, must receive experimental investigation. Only the agricultural experiment stations and a few large growers are equipped to perform the necessary tests to determine their comparative merits.

Each grower must determine for himself the economy of using any of these ingredients, or whether he can afford to use synthetic compost at all since its cost must necessarily be high in comparison to manure when that is plentiful. He may find, however, as some have, that a properly made synthetic compost added to manure will assure him more uniform yields year in and year out than will manure alone. In such a case the cost of the synthetic compost, if it approximates that of manure, is a secondary consideration.

EXPERIMENTAL PROCEDURE

Conditions for composting.—The piles were composted in the open air. The composting ground was packed and well drained. No water ever stood around the piles. When composting was done during the winter, a layer of straw or wooden barriers were placed on the north and west sides of the piles. This was necessary because the composting ground was exposed to strong northwest winds which prevented natural thermogenesis from raising the temperature of the small piles to the required point. With this protection composting could be carried on satisfactorily at any season.

The piles stood side by side with no separation other than the cleavage made by turning each pile as a separate unit. This caused a sharp line to form between the piles that made them easily separable at the next turning. The piles were built 3 to 4 feet high and never more than 6 feet wide.

At the end of the composting period, before the material was taken into the house, it was turned and mixed thoroughly. Each plot was then filled with a definite weight of finished compost.

During the composting process, the temperature within the individual piles varied greatly, depending on the part of the pile tested; hence, only wide temperature variations between the piles were significant. Such pronounced variations were better recorded by observation than by actual figures. Differences important in interpreting results are presented. Other physical and chemical properties also varied within the piles before turning..

Undoubtedly this variation is important and the final mixture used to fill the beds combines all the variants. Thus, compost that is very dry and "fire-fanged" becomes mixed during the final turning with compost that is very wet. Although proportions may thus be balanced and the moisture content may be judged satisfactory, this does not necessarily mean that one part of the pile is as well adapted to mushroom growing as another. Apparently an additional composting period in the beds after filling reduces the effect of this variation to some extent, but only if the temperature of the beds is very uniform from top to bottom.

Composting under conditions of continuous mixing as described by Stoller, Smith and Brown *(8)* may reduce this variation. The effects of this method cannot be translated readily into terms of commercial practice since the process itself introduces another factor.

Conditions for growing mushrooms in beds.—The tests of materials and composts were made in the small experimental mushroom house at the Experiment Station provided by the Mushroom Growers Cooperative Association of Pennsylvania. The original building was described in a previous publication by Hein *(4)*. Since then the building has been doubled in size by the same Association. In addition, automatic temperature control equipment has been added, making it possible to continue the experiments throughout the year with little temperature variation. Before this equipment was installed it was impossible to prevent serious fluctuations in temperature and the results of several experiments were too variable to have much significance.

The bed space in which the composted materials were tested for mushroom production was divided into 30 plots of 9 square feet each. These plots were arranged in two series of beds three tiers high with five plots in each series on each tier. The tiers were 30 inches apart vertically and the bottom tier was 1 foot above the ground. Six variations of compost were compared in five replications. The plots were randomized except that each treatment appeared in every row of plots but one. This plan was found to yield

results which were not adapted to the best determination of significance by analysis of variance. Therefore, in the later experiments only five types of compost were compared in six replications, each material then appearing once in each row of beds. Where possible all results have been subjected to analysis of variance to determine their significance.

Fig. 1.—Experimental mushroom house.
This house was donated to the Experiment Station by the Pennsylvania Mushroom Growers Cooperative Association.

Lambert *(7)* found that under commercial conditions, because of the methods of filling, the greatest significance was obtained from any set of yield data by treating two adjacent bays or sections of bed as one plot. There was no evidence of a need for such a treatment in our experiments. This was probably because much more uniform mixing of the material and filling of the beds was possible in our experiments than is possible in a commercial house.

The volume of air space and the heat loss through the walls of the experimental house were so great compared to the volume of compost that thermogenesis of the material after the beds were filled was insufficient to raise the temperature higher than 100° F. This heat was, therefore, supplemented with live steam allowed to escape into the room. The temperature of the beds was raised by this method to 130° F where it was kept for 24 hours. It was then allowed to decrease gradually to 70° F, at which temperature the spawn was planted.

The temperature was maintained at 70° to 73° F for 2 weeks after the spawn was planted. At the end of this time each plot was cased with 65 pounds of dry soil. The temperature was lowered gradually to 60° F during the 2 weeks after casing. As far as possible the temperature was maintained at 55° to 60° F while the beds were in production. Some variations were unavoidable and at times they were sufficient to interfere seriously with the yields.

The beds were watered frequently since the large volume of air space compared to bed area resulted in much greater water loss than occurs in commercial houses. Watering was especially important on the lower beds which required daily sprinkling to be kept in production.

Grain spawn.—After a preliminary comparison with bottled manure spawn as produced commercially in Chester county, the spawn used throughout the experiments was made with grain as a base.[1] Grain spawn has several advantages over the old manure type. Among these are ease of preparation, uniformity of growth throughout the containers, uniformity in amount and distribution of spawn in the bed, and ease of handling, including ability to remove spawn from an unbroken container. In addition, the mycelium from this spawn grows more rapidly in the beds, thus bringing the beds into production a week earlier than when planted with manure spawn.

Computation of results.—To make the results of the successive experiments comparable, several measures new to the mushroom industry were adopted. The results cannot be placed directly on a cost basis as the price of the various ingredients entering into the compost varies with the season and with the locality.

Growers usually compute yields on the basis of pounds of mushrooms per square foot of bed space. This figure, in itself, may be of small importance. The beds may vary so much in thickness and the manure in loss of original weight that such a standard is often misleading. The grower who reports high yields per square foot may be filling much less area per ton of manure bought than his neighbor whose crop per square foot is less but whose actual yield per ton of manure may be considerably higher. In Chester county,

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[1] The process of making grain spawn is protected by patents 1,869,517 and 2,044,861 owned by the Pennsylvania Research Corporation. For information concerning license to make and sell this product, address S. K. Hostetter, Secretary, Pennsylvania Research Corporation, State College, Pa.

In making this spawn, rye and water are placed in flasks or bottles in equal portions by volume or 2 parts of grain to 3 parts of water by weight. To this is added calcium carbonate as precipitated chalk in the proportions of 1 part to 50 parts of grain by weight. The containers are stoppered with cotton and sterilized a half hour under 17 pounds steam pressure. Inoculation is made either from a stock culture maintained on agar or from a bottle of the grain previously overgrown with mycelium of the mushroom. The bottles are shaken after 8 days' growth to mix the grain thoroughly. This type of spawn is ready to plant in 10 to 14 days after inoculation, depending on temperature and amount of inoculum introduced. When an agar culture is used for transfer into the grain the growth is slower.

Pennsylvania, where the cost of the manure may be half the total cost of production, this difference in yield from a unit of manure is especially important.

The results recorded here are presented on the basis of yield per unit mass of material. The first unit used is a pound of organic matter at filling time; the second is comparable weights of original ingredients. The synthetic compost piles usually consisted of 500 pounds of dry straw to which the other ingredients were added. This produced an amount of compost about equal in bulk to that obtained from 1 ton of fresh horse manure.

The total weight of the pile was recorded at filling time and samples were taken from which the moisture and ash content were determined. The remainder was considered to be organic matter. Dry weight was determined at 218° F, ash weight at 932° F. Since fresh weights were necessarily used in filling the beds it was impossible to obtain equal dry weights per plot of the different materials. Adjustment of the fresh weights per plot to allow for differences of bulk and moisture content were attempted, but in all cases, some variation between the dry weights of the plots from different types of compost occurred. This again showed the necessity of determining yields on a weight rather than an area basis. The synthetic composts tended to be more bulky than manure; hence it was impossible in many cases to pack the same fresh weight of different materials in the beds though all plots filled from one pile contained an equal weight of compost.

The mushrooms were picked every day when abundant or on alternate days between breaks. Each plot was treated as a unit and the mushrooms from it picked, weighed and counted separately. The bases of the stems were cut away to remove the soil without reducing more than necessary the weight of the mushrooms. Yields were determined as pounds of fresh mushrooms per plot. From this figure yields per unit of organic matter and yields per unit weight of original ingredients were calculated.

Although some deviations occurred from the procedure as outlined, the experiments have followed closely one pattern. In some cases, materials other than synthetic composts were included in the tests, but the results will be reserved for later publication. The experiments are presented in chronological order as they were performed.

EXPERIMENTS AND RESULTS

Before research on synthetic combinations could be undertaken, it was necessary to know something of the ingredients of manure which make it a favorable medium for mushrooms growing. The first experiment was designed to give this information.

Effect of droppings and bedding straw on mushroom production. —Growers have always considered droppings an essential part of the horse manure used in mushroom growing. To find whether this is true, a preliminary test of horse manure was made. Droppings were separated daily from the straw and urine as the manure was taken from the stable. After sufficient amounts had been secured, they were taken to the composting ground and arranged in piles by fresh weight as follows:

Pile 1.—900 pounds droppings only

Pile 2.—600 pounds droppings and 267 pounds of bedding straw

Pile 3.—300 pounds droppings and 533 pounds of bedding straw

Pile 4.—800 pounds bedding straw only

The piles were kept outside for 41 days. During the first part of this period they were too dry to decompose rapidly; consequently the period of active composting was about 31 days. The beds were planted 9 days after they were filled, the temperature meantime having been above 120° F for 3 days. One side of the house was cased 26 days, the other 35 days after planting. The yield of the two sides was not significantly different.

Table 1.—Combinations of bedding straw and droppings. Yield of mushrooms in pounds per bed.

	Per Cent Mixture by Fresh Wt. Bed. Straw	Per Cent Mixture by Fresh Wt. Droppings	Tier 1	Tier 2	Tier 3	Sum of 3 Tiers	Pile Mean
Pile 1	0	100	12.38	19.76	20.15	52.29	17.43
Pile 2	30.8	69.2	13.65	21.15	21.57	56.37	18.79
Pile 3	64.0	36.0	11.71	18.68	26.09	56.48	18.83
Pile 4	100.0	0	10.56	16.63	22.42	49.61	16.54
Sum of piles			48.30	76.22	90.23	214.75	
Tier mean			12.08	19.06	22.56		

ANALYSIS OF VARIANCE:

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square
Total	11	263.00	
Between piles	3	11.19	3.73
Between tiers	2	227.83	113.92
Interaction	6	23.99	3.99

Standard deviation 2.00

Standard error of difference between any pair of tier means: $2.0 \times 2/4 = 1.414$

Approximate significant difference between any pair of tier means: $1.414 \times 2.447 = 3.46$

The yields from the various combinations of droppings and bedding straw did not differ significantly, table 1. It may be concluded that urine-soaked bedding straw, droppings, or any combination of the two may be used for commercial mushroom growing. In this experiment the yield was best on the top tier and poorest on the bottom. The steam pipes caused this difference in yield by drying

out the back part of the bottom and middle tiers and maintaining them at too high a temperature.

When the yields on the several combinations of bedding straw and droppings are divided into breaks,[2] an affect of material on yield is apparent, table 2. Where droppings alone are present the yield is very high at first but diminishes rather rapidly. As bedding

Table 2.—Combinations of bedding straw and droppings. Yield by breaks in pounds per bed.

BREAK NO.	PILE 1	PILE 2	PILE 3	PILE 4
1	4.883	4.381	4.160	2.008
2	3.516	4.433	3.481	3.175
3	2.152	2.551	2.458	2.013
4	1.662	1.744	2.247	2.194
5	1.473	1.343	1.656	1.812
6	1.025	1.005	1.019	1.402
7	0.882	0.807	0.899	1.138
8	0.606	0.516	0.642	0.591
9	0.483	0.571	0.827	0.820
10	0.428	0.397	0.941	0.723
11	0.320	0.597	0.492	0.657

straw is added in increasing amounts, the yield of the first break becomes less but the yields at the end of the crop are larger. Thus a very strawy manure would be expected to yield a more steady crop over a longer period than a manure rich in droppings, but the total crop produced would be no greater. Since the analysis of variance showed that there were no significant differences in total yield, it is assumed that the differences between the production in the various breaks would be significant.

Preliminary trial of synthetic compost.—For this experiment, straw, urea and wheat were used as basic ingredients. Since straw is abundantly available in most localities and forms the bulk of the horse manure used for mushroom growing, the reason for its choice is obvious. Wheat straw was the only kind used in the first series of experiments to avoid the introduction of an additional variable.

Of the many nitrogen compounds available, such as ammonium phosphate and sulphate, potassium and sodium nitrate, calurea and cyanamide, urea was chosen. Urea contains 45 per cent nitrogen. On the basis of its nitrogen content, it costs little more than the other nitrogenous fertilizers. It is readily decomposed by the action of microorganisms into ammonia and carbon dioxide, leaving no inorganic residue which might interfere with the decomposition process, or of mushroom development later.

[2] The terms "break" and "flush" are used in the Pennsylvania mushroom growing area to mean that part of the crop appearing on the beds at any time. These breaks occur as successive waves of production, the amount decreasing with the age of the beds.

Since manure from horses fed grain or concentrates heats much better in the pile and retains its thermogenic capacity much longer

Table 3.—Preliminary experiment on synthetic compost. Material as used to fill the beds.

	PILE 1	PILE 2	PILE 3
Fresh weight per bed	100 lbs.	100 lbs.	100 lbs.
Dry weight per bed	35.62 lbs.	32.41 lbs.	44.90 lbs.
Ash weight per bed	4.78 lbs.	2.76 lbs.	9.29 lbs.
Organic matter* weight per bed	30.84 lbs.	29.65 lbs.	35.61 lbs.
Amount of moisture†	180.74%	208.55%	122.72%
Space filled per ton of straw	285 sq. ft.	358 sq. ft.	....
Organic matter per square foot	3.43 lbs.	3.29 lbs.	3.96 lbs.

* Dry weight minus the ash weight.

† Moisture was determined as per cent on the basis of dry weight. While this may seem confusing at first, it provides a much better basis for comparison. Corresponding figures for per cent of moisture based on fresh weights are: pile 1, 64.38; pile 2, 67.59; and pile 3, 55.10. These figures do not indicate the really wide differences in moisture content between the piles.

than manure from horses fed on a low protein diet, it was decided to include grain as one of the basic ingredients of the synthetic compost. Wheat was chosen as a convenient form of grain even though it is expensive under ordinary conditions. If it proved a valuable addition to the compost, however, grain by-products such as bran, wheat screenings, brewers' and distillers' grains and low-grade grain, such as smutty or soft wheat, could be easily substituted at a cost low enough to be commercially practical. In the series of experiments reported here these substitutes were not used. They were used in a subsequent series, the results of which will be reported in a later publication.

Two piles of straw were used, containing 450 pounds each. These were thoroughly wetted and tramped down solidly. Six days later the piles were turned and wheat and urea were added in the following amounts:

	PILE 1	PILE 2
Straw	450 lbs.	450 lbs.
Urea	5 lbs.	10 lbs.
Wheat	131 lbs.	263 lbs.

The wheat was soaked overnight before being added.

The piles were turned three more times at intervals of 7 days, and the house was filled 4 days after the last turning. This made the composting period 30 days. At the same time a pile of horse manure was composted and used for comparison. This is pile 3.

Table 3 gives information concerning the materials at the time the beds were filled. The yield data showing the total yields in

Table 4.—Preliminary experiment on synthetic compost. Yield in pounds per bed.

PLOT	PILE 1	PILE 2	PILE 3
1	14.73	2.21	18.67
2	15.04	2.53	23.32
3	11.23	4.32	19.14
4	16.24	5.86	25.99
5	12.83	5.08	18.61
Total of 5 plots	70.07	20.00	105.73
Mean	14.01	4.00	21.15

ANALYSIS OF VARIANCE:

Source of Variation	Degree freedom	Total square	Mean square	Standard deviation
Total	14	812.43		
Between piles	2	741.88	370.94	
Within piles	12	70.54	5.88	2.424

Standard error of difference between pair of pile means:
$2.424 \times \sqrt{1/5 + 1/5} = 1.532$

Approximate significant difference between piles: 5% $= 1.532 \times 2.179 = 3.338$

pounds per bed are presented in table 4, while table 5 shows the yield per pound of organic matter present at the time of filling.

The differences between these piles are all significant, whether figured on the basis of pounds per bed or as pounds of mushrooms per pound of organic matter. The yield was largest from manure. The first pile of synthetic compost, containing 22 pounds of urea and 482 pounds of wheat per ton of straw, produced two-thirds as many mushrooms as manure per bed and three-quarters as many per pound of organic matter. The second pile of synthetic compost, containing twice as much urea and wheat, produced a very small crop. It was later discovered that too much urea had been added. This prevented the development of the micro-organisms and the pile underwent little decomposition.

The first pile produced 444 pounds of mushrooms per ton of straw used. This corresponds to about one and a half pounds of mushrooms per square foot.

Effect of adding wheat to synthetic compost.—Since nothing was known about the relative importance of the various ingredients of this compost for the production of mushrooms, experiments were undertaken to determine their value.

The addition of wheat was studied first. Five piles of wheat straw were started, using 500 pounds of straw per pile. They were tramped and wetted thoroughly. A pile of manure was started at

Table 5.—Preliminary experiment on synthetic compost. Yield in pounds of mushrooms per pound of organic matter present.

PLOT	PILE 1	PILE 2	PILE 3
1	0.477	0.075	0.525
2	0.488	0.086	0.656
3	0.400	0.146	0.538
4	0.525	0.198	0.731
5	0.417	0.172	0.523
Total of 5 plots	2.307	0.677	2.973
Mean	0.461	0.135	0.595

ANALYSIS OF VARIANCE:

Source of Variation	Degree freedom	Total square	Mean square	Standard deviation
Total	14	0.615884		
Between piles	2	0.558138	0.279069	
Within piles	12	0.057746	0.004812	0.0694

Stand. err. between any pr. pile means $= 0.0694 \times \sqrt{1/5 + 1/5} = 0.04386$
Appr. sign. dif. between any pr. pile means 5% val. $= 0.04386 \times 2.179 = 0.095$

the same time, but since it was insufficiently composted when the synthetic materials were ready, the yields from it were too low to be of comparative value.

Urea was added to the straw piles at the first turning, 6 days after they were started, at the rate of 5 pounds per pile or 20 pounds per ton of straw. This was sprinkled as a solution of 1 pound per gallon as evenly as possible throughout the piles while they were

Table 6.—Variation of wheat content in mushroom compost. Material used to fill the beds.

	PILE 1	PILE 2	PILE 3	PILE 4	PILE 5
Fresh weight per bed	70 lbs.	70 lbs.	70 lbs.	70 lbs.	70 lbs.
Dry weight per bed	25.14 lbs.	21.03 lbs.	16.54 lbs.	15.92 lbs.	16.75 lbs.
Ash weight per bed	2.36 lbs.	2.47 lbs.	1.57 lbs.	1.73 lbs.	1.41 lbs.
Organic matter weight per bed	22.78 lbs.	18.56 lbs.	14.97 lbs.	14.19 lbs.	15.34 lbs.
Amount of moisture	178.44 %	232.86 %	323.22 %	339.70 %	317.91 %
Space filled, sq. ft. per ton of straw	522.0	347.0	562.0	700.0	620.0
Organic matter per sq. ft.	2.531 lbs.	2.062 lbs.	1.663 lbs.	1.577 lbs.	1.704 lbs.
Total organic matter per ton of straw	1311.2 lbs.	716.0 lbs.	934.4 lbs.	1102.8 lbs.	1056.8 lbs.

being turned. Water was added at the same time and the piles were tramped during the turning.

Wheat which had been soaked over night was added at the next turning in the following proportions:

PILE NO.	WHEAT AS DRY GRAIN ADDED PER PILE	PER TON OF STRAW
1	200 lbs.	800
2	150 lbs.	600
3	100 lbs.	400
4	50 lbs.	200
5	0 lbs.	0

This was 6 days after the urea had been added. The grain was thrown into the pile during the turning and some additional water added. The piles were tramped after the turning was completed.

The piles were again turned after 7, 14 and 21 days and were placed in the beds 3 days after the last turning, or 35 days from the time they were started. Table 6 gives information on the piles at the time the beds were filled.

The yield of mushrooms on the composts containing varying amounts of wheat has been computed on three different bases. Table 7 presents the yields as total pounds per plot of 9 square feet. On this basis the yield of mushrooms obtained per unit area is

Table 7.—Variation of wheat content in mushroom compost. Yield in pounds per bed.

PLOT	PILE 1	PILE 2	PILE 3	PILE 4	PILE 5	
1	8.499	7.747	6.464	7.070	5.893	
2	10.454	7.088	5.602	6.777	4.980	
3	7.496	7.467	5.895	6.085	2.238	
4	6.980	5.355	7.665	4.350	5.626	
5	7.075	7.240	5.750	5.503	3.426	
Total 5 plots	40.454	34.897	31.376	29.785	22.163	158.675
Mean per pile	8.091	6.979	6.275	5.957	4.432	

ANALYSIS OF VARIANCE:

Source of Variation	Degree Freedom	Total Sq.	Mean Sq.	F. value
Total	24	66.2831		
Between piles	4	36.3143	9.0768	5.86
Within piles	20	30.9688	1.54844	

Standard deviation: 1.244
Stand. err. of dif. between pr. of pile means: 0.78677
Appr. least sig. dif. between any pr. of pile means: 1.641

directly proportional to the amount of wheat added. The analysis of variance shows that while the difference in yield between any two adjacent piles is not significant, the difference between alternate piles is significant. On the basis of yield per unit area, then, the grower would be justified in adding a large quantity of wheat to his compost.

Table 8.—Variation in wheat content as affecting yield. Yields in pounds per pound of organic matter.

PLOT	PILE 1	PILE 2	PILE 3	PILE 4	PILE 5	
1	.3730	.4167	.4318	.4982	.3842	
2	.4589	.3813	.3742	.4776	.3246	
3	.3291	.4016	.3938	.4288	.1459	
4	.3064	.2880	.5120	.3066	.3668	
5	.3106	.3894	.3841	.3878	.2233	
Total 5 plots	1.7789	1.8770	2.0959	2.0990	1.4448	9.2947
Mean per pile	0.3556	0.3754	0.4191	0.4198	0.2890	

ANALYSIS OF VARIANCE:

Source of Variation	Degree Freedom	Total Sq.	Mean Sq.	F. value
Total	24	.15653		
Between piles	4	.05843	0.01461	2.978
Within piles	20	.09810	0.004905	

Standard deviation: 0.07003
Stand. error of diff. between pr. of pile means: 0.044291
Appr. least sign. diff. between pr. of pile means: 0.09239

When the yield is based on the weight of mushrooms obtained per pound of organic matter in the compost, a very different result is obtained. On this basis the piles containing the least amount of wheat produced the most mushrooms. The only significant difference is that between all the piles containing wheat as compared to the pile containing no wheat.

The piles containing the most wheat yielded a greater total weight of mushrooms only because their organic content was larger. From table 6 it is obvious that the moisture content of piles one and two, which contained the most wheat, is less than that of the others. When 70 pounds of fresh material were placed in each bed, more organic matter was present in the drier composts for the mushroom mycelium to use as food. The yield per pound of organic matter present becomes, then, a much better index to the effect of addition of wheat than does the yield per unit area. On this basis, the addition of some wheat is an advantage, but the amount added need not be large.

When the yields are computed on the basis of pounds of mushrooms produced per ton of dry straw, table 9, a still different result is obtained. On this basis piles 1 and 4, which contained the most and least wheat respectively, gave the best production although

they were not significantly better than pile 3 which contained the next lowest amount of wheat. Since pile 1 contained four times as much grain as pile 4, the results are surprising. It appears again that the addition of much grain is not profitable although the presence of some grain is an advantage. Pile 2 composted much faster than the others, leaving much less for filling beds. This would make

Table 9.—Variation in wheat content as affecting yield. Yield in pounds per ton dry straw.

PLOT	PILE 1	PILE 2	PILE 3	PILE 4	PILE 5	
1	492.9	298.7	403.6	549.9	406.0	
2	606.3	273.3	349.8	527.1	343.1	
3	434.8	287.9	368.1	473.3	154.2	
4	404.8	206.5	478.6	338.3	387.6	
5	410.4	279.1	359.1	428.0	236.0	
Pile totals	2349.2	1345.5	1959.2	2316.6	1526.9	9497.4
Pile means	469.8	269.1	391.8	463.3	305.4	

ANALYSIS OF VARIANCE:

Source of Variation	Degree Freedom	Total Sq.	Mean Sq.	F. value
Total	24	284,098.71		
Between piles	4	165,102.67	41,275.67	6.94
Within piles	20	118,996.04	5,949.80	

Standard deviation: 77.134
Stand. error of diff. between pr. of pile means: 48.784
Appr. least sig. dif. between pr. of pile means: 101.76

the yield from this pile not strictly comparable to that from the other beds. The effect of rate of composting will be further discussed later.

Effect of adding urea to synthetic compost.—The next variable studied was the urea content. In this experiment the time of composting and amount of wheat added remained constant. Each pile contained 500 pounds of baled straw, thoroughly wetted and tramped. After 6 days urea was added in the following amounts:

PILE NO.	UREA ADDED
2	0 lbs.
3	4 lbs.
4	8 lbs.
5	12 lbs.
6	16 lbs.

Pile 1 consisted of 1 ton of horse manure which was started to compost at the same time the urea was added to the synthetic piles.

All the piles were turned again after 6 days and 100 pounds of

wheat, dampened 24 hours previously, added to each straw pile. The piles were given three more turnings at intervals of 7, 8 and 8 days, respectively. The composting was done during November and December and the piles had no protection from strong northwest winds. This made the composting slower. The straw lay a total of 44 days before it was placed in the beds, or 27 days after the wheat was added. The manure lay 38 days.

Table 10.—Variation of urea content in mushroom compost. Material as used to fill the beds.

	PILE 1	PILE 2	PILE 3	PILE 4	PILE 5	PILE 6
Fresh weight per bed	125 lbs.	80 lbs.	80 lbs.	100 lbs.	70 lbs.	60 lbs.
Dry weight per bed	25.4 lbs.	16.7 lbs.	16.8 lbs.	18.5 lbs.	17.5 lbs.	13.8 lbs.
Ash weight per bed	5.14 lbs.	1.05 lbs.	1.59 lbs.	1.70 lbs.	1.10 lbs.	.66 lbs.
Organic matter weight per bed	20.26 lbs.	15.65 lbs.	15.21 lbs.	16.80 lbs.	16.40 lbs.	13.14 lbs.
Amount of moisture	392.1%	379.0%	376.2%	440.5%	300.0%	334.8%
Space filled, ton of straw, per sq. ft.	76.2*	473.2	536.0	388.8	623.2	818.8
Total organic matter per ton of straw	171.4* lbs.	822.4 lbs.	905.6 lbs.	725.2 lbs.	1134.8 lbs.	1197.6 lbs.

* Per ton of manure.

At the time of filling the condition of the several piles was as follows:

PILE 1.—Slightly over-composted, dark brown.

PILE 2.—Under-composted; slightly warm at center; straw brown but with tensile strength nearly as great as new straw.

PILE 3.—Slightly under-composted; pile warm.

PILE 4.—Composted sufficiently; very hot.

Table 11.—Variation of urea content in mushroom compost. Yield in pounds of mushrooms per bed.

TIER	PILE 1	PILE 2	PILE 3	PILE 4	PILE 5	PILE 6	SUM TIERS	MEAN TIER
1	8.144	1.424	2.961	3.078	3.373	1.160	20.140	3.357
2	8.283	2.590	3.126	6.482	3.675	3.618	27.774	4 629
3	11.034	3.810	3.982	5.443	4.828	5.644	34.741	5.790
Sum of tiers	27.461	7.824	10.069	15.003	11.876	10.422	82.655	
Mean per pile	9.154	2.608	3.356	5.001	3.959	3.477		

ANALYSIS OF VARIANCE:

Source of Variation	Degree Freedom	Sum of Sq.	Mean Sq.	F. value
Total square	17	110.3818		
Between piles	5	84.2707	16.8541	20.22
Between tiers	2	17.7781	8.8890	10.67
Interaction	10	8.3329	.8333	

Standard deviation: 10.9128
Standard error between pr. of pile means: 0.7453
Appr. least sig. dif. between any pr. of pile means: 1.660

PILE 5.—Under-composted; warm; straw retaining tensile strength.

PILE 6.—No composting; color of new straw; cold; unchanged.

Table 10 shows the relation between the piles at the time the beds were filled.

The beds were planted with grain spawn 5 days after they were filled and were cased 23 days after the spawn was planted. Because of the lack of temperature control equipment, the temperature was

Table 12.—Variation of urea content in mushroom compost. Yield in pounds of mushrooms per pound of organic matter.

TIER	PILE 1	PILE 2	PILE 3	PILE 4	PILE 5	PILE 6	SUM OF PILES	MEAN PER TIER
1	0.4020	0.0910	0.1947	0.1832	0.2057	0.0882	1.1648	0.1941
2	0.4088	0.1655	0.2055	0.3858	0.2241	0.2753	1.6650	0.2775
3	0.5446	0.2434	0.2618	0.3240	0.2944	0.4295	2.0977	0.3496
Sum of tiers	1.3554	.4999	.6620	.8930	.7242	.7930	4.9275	
Mean per pile	0.4518	0.1666	0.2207	0.2977	0.2414	0.2643		

ANALYSIS OF VARIANCE:

Source of Variation	Degree Freedom	Sum of Sq.	Mean Sq.	F. value
Total square	17	0.254624		
Between piles	5	0.143102	0.28620	73.63
Between tiers	2	0.072652	0.03633	9.35
Interaction	10	0.038870	0.003887	

Standard deviation: 0.062346
Standard error between pr. of pile means: 0.0509
Appr. least sig. dif. between pr. of pile means: 0.1134

inadvertently allowed to rise above 90° F for several days before the casing soil was applied. The drying effect of this high temperature materially reduced the yields except on the beds containing manure, which, being more compact, did not lose moisture so rapidly. This effect on yield was most pronounced in the lower beds, table 11. To find the effect on yield of varying the amount of urea, it was necessary to include in the analysis of variance the effect of position of the beds in the house. The results were combined for each tier and are presented on that basis. This reduced the number of samples and degrees of freedom so much that the results are not very significant. The results are presented on the three bases used in the previous experiment, tables 11, 12 and 13.

Manure outyielded the synthetic compost both as to pounds per bed and weight per pound of organic matter. Probably this is chiefly because it did not lose moisture rapidly. Pile 4, containing 32 pounds of urea per ton of straw, was apparently the best of the synthetic composts although it did not yield significantly more

than any except pile 2 where no urea was present. The yields were so variable that no significant figures were obtained between the piles on a per ton of straw basis.

Table 13.—Variation of urea content in mushroom compost. Yield in pounds of mushrooms per ton of dry straw.

Tier	Pile 2	Pile 3	Pile 4	Pile 5	Pile 6	Sum of Piles	Mean per Tier
1	74.9	176.3	133.0	233.6	105.5	723.3	144.7
2	136.2	186.2	280.0	254.5	329.1	1186.0	237.2
3	200.3	237.1	235.1	334.3	513.5	1520.3	304.1
Sum of tiers	411.4	599.6	648.1	822.4	948.1	3429.6	
Mean per pile	137.1	199.9	216.0	274.1	316.0		

Analysis of Variance:

Source of Variation	Degree Freedom	Sum of Sq.	Mean Sq.	F. value
Total square	14	167,682.85		
Between piles	4	57,201.58	14,300.4	2.46
Between tiers	2	64,088.08	32,044.0	5.53
Interaction	8	46,393.19	5,799.2	

From the observations on rate and amount of decomposition of the piles it appears that 32 pounds of urea per ton of straw are the maximum which may be added advantageously at one time. Increased amounts reduce the composting rate, probably by preventing the growth of microorganisms. Pile 6 did not decompose at all, yet the mycelium was able to grow in it and yield a rather large weight of mushrooms per pound of organic matter and per ton of straw. *Psalliota campestris* is apparently less susceptible to high concentrations of urea than the other organisms. Perhaps it does not ammonify the urea, at least rapidly, and thus does not release toxic quantities of ammonia. More than 32 pounds of urea per ton of straw undoubtedly could be added without interfering with the composting rate if added over a period of several weeks rather than all at once. This was not attempted in this experiment.

Effect of composting time on artificial manure.—Previous experiments indicated that the effect of decomposition might be an important factor in limiting the yield of mushrooms from certain raw materials.

It was necessary to start the compost piles for this experiment at intervals so that all the beds could be filled at once. A preliminary experiment was undertaken to find what might be the effect of this time variation since all the piles would not be exposed to the same environmental conditions. An interval of 4 days was chosen. The piles were made up of the following ingredients: wheat straw, 500 pounds; urea, 8 pounds; and wheat, 120 pounds.

The piles were started by watering and compressing the straw.

Four days later urea was added. Four days later the wheat was added. The piles were then turned at 8-day intervals until the experiment was concluded. The piles were then weighed and samples taken from which dry weights, moisture content and ash could be determined, table 14.

The greatest loss in weight occurred during the first 30 days; little or no loss occurred subsequently. Between the twenty-first and

Fig. 2.—Loss of manure during composting.
(1) Uncomposted manure; (2) after 16 days of composting; loss in dry weight, 30 per cent; (3) after 39 days of composting; loss in dry weight, 52 per cent.

thirtieth days, there was a loss of 89 pounds per pile or nearly one-third of the dry weight remaining after 21 days of composting. Unless this loss is compensated by conversion of ingredients during the decomposition into substances essential to the development of

Table 14.—Effect of varying time of composting on weight of piles of synthetic compost.

	PILE 1	PILE 2	PILE 3	PILE 4	PILE 5
Composting time	38 days	34 days	30 days	25 days	21 days
Fresh weight at end	763 lbs.	983 lbs.	867 lbs.	1057 lbs.	1120 lbs.
Dry weight at end	200 lbs.	199 lbs.	204 lbs.	252 lbs.	293 lbs.
Amount of moisture	282%	394%	325%	319%	282%
Ash weight	29 lbs.	27.6 lbs.	26.3 lbs.	26.0 lbs.	
Ash	14.5%	13.9%	12.9%	10.3%	
Total organic matter per ton of straw	684 lbs.	685.6 lbs.	710.8 lbs.	904.0 lbs.	

the mushroom mycelium, a composting period longer than 21 days is not justified.

To test this point the experiment was repeated and the resulting composts were used for growing a crop. The piles consisted of 500 pounds of straw, 8 pounds of urea and 120 pounds of wheat. Com-

Table 15.—Varying the time of composting. Material as used to fill the beds.

	PILE 1	PILE 2	PILE 3	PILE 4	PILE 5	PILE 6
Composting time	36 days	33 days	29 days	Manure	25 days	21 days
Fresh weight of pile at filling time	1015 lbs.	831 lbs.	1014 lbs.		1222 lbs.	1183 lbs.
Dry weight of pile at filling time	220 lbs.	182 lbs.	233 lbs.		280 lbs.	276 lbs.
Amount of moisture	353.1%	359.1%	335.2%	220.7%	333.3%	328.6%
Ash weight	29.2 lbs.	25.1 lbs.	26.9 lbs.		29.5 lbs.	30.3 lbs.
Ash per cent of dry weight	13.3	13.8	11.5	18.8	10.5	11.0
Fresh weight per bed	110 lbs.	100 lbs.	90 lbs.	110 lbs.	80 lbs.	90 lbs.
Dry weight per bed	23.8 lbs.	21.9 lbs.	20.7 lbs.	34.3 lbs.	18.3 lbs.	21.0 lbs.
Ash weight per bed	3.2 lbs.	3.0 lbs.	2.4 lbs.	6 5 lbs.	1.9 lbs.	2.3 lbs.
Organic matter per bed	20.6 lbs.	18.9 lbs.	18.3 lbs.	27.8 lbs.	16.5 lbs.	18.7 lbs.
Total space filled per ton of straw, sq. ft.	332	298	406		550	473
Organic matter per ton of straw	763.2 lbs.	627.6 lbs	824.4 lbs		1002.0 lbs.	982.8 lbs.

posting of the first pile started on August 8, 1933, and the beds were filled September 13. The piles were started 4 days apart, the urea being added 4 days after the pile was made up and the wheat 4 days later. Data on the piles at filling time are given in table 15.

The rate of composting in this experiment lacked the uniformity

Table 16.—Varying the time of composting. Yield in pounds of mushrooms per bed.

	PILE 1	PILE 2	PILE 3	PILE 4	PILE 5	PILE 6	
	4.62	3.23	2.02	2.92	2.90	3.17	
	3.48	1.08	1.00	2.20	5.19	1.76	
	2.50	1.15	1.66	5.06	5.03	5.16	
	.60	.84	2.22	3.17	6.05	5.33	
	2.02	.05	1.64	3.17	4.62	5.59	
Sum of 5 plots	13.22	6.35	8.54	16.52	23.79	21.01	89.45
Mean per pile	2.64	1.27	1.71	3.30	4.76	4.20	

ANALYSIS OF VARIANCE:

Source of Variation	Degree Freedom	Sum of Sq.	Mean Sq.	F Value
Total square	29	83.7291		
Between piles	5	47.0726	9.4145	6.16
Within piles	24	36.6565	1.5274	

Standard deviation: 1.236
Stand. error of dif. between pr. of pile means: 0.7816
Appr. least sign. dif. between pr. of pile means: 1.613

obtained in the previous trial but the trend toward rapid decomposition between the twenty-first and thirtieth days was the same. During the composting period, several heavy rains fell. These may have affected variously the rate of composting, depending on the condition of the piles at the time of the rain. In an attempt to obtain equal bulk of material in the beds the weight per bed was varied. As a result, slightly different weights of organic matter per bed were used from the piles.

Table 17.—Varying the time of composting. Yield in pounds of mushrooms per pound of organic matter.

	Pile 1	Pile 2	Pile 3	Pile 4	Pile 5	Pile 6	
	.2241	.1710	.1101	.1051	.1768	.1697	
	.1686	.0572	.0548	.0790	.3164	.0939	
	.1213	.0607	.0909	.1817	.3069	.2757	
	.0293	.0446	.1210	.1138	.3686	.2850	
	.0981	.0028	.0898	.1137	.2816	.2988	
Sum of 5 plots	.6414	.3363	.4666	.5933	1.4503	1.1231	4.6110
Mean per pile	.1283	.0673	.0933	.1387	.2901	.2246	

Analysis of Variance:

Source of Variation	Degree Freedom	Sum of Sq.	Mean Sq.	F Value
Total square	29	.28045		
Between piles	5	.18308	.03652	9.0
Within piles	24	.09737	.00406	

Standard deviation: 0.0637
Stand. error of dif. between pr. of pile means: 0.0403
Appr. sig. dif. between pr. of pile means: 0.0831

The yields, tables 16, 17 and 18, are all low because of temperature variations in the experimental house. In spite of low total weights the differences in yield are large enough to be significant.

The piles composted 21 and 25 days produced more mushrooms than those composted longer, whatever the basis of comparison. When compared on the basis of pounds of mushrooms per ton of straw, pile 5, composted only four days less than pile 3, produced nearly four times as much. Some difference might be expected since at the end of the composting period pile 5 contained 178 pounds, or 20 per cent more organic matter per ton of straw used and would fill 150 square feet more of bed than would pile 3, table 15. This, however, does not account for the large difference in yield. Apparently two factors contribute to the adverse effect on yield of prolonged composting: first, the reduction in total organic matter during the composting process, and second, a specific effect on the subsequent development of the mushroom. The latter may be a limiting factor resulting from the loss, by decomposition, of some specific substance necessary for the extensive growth of the mycelium, or it may be a retarding factor resulting from the pro-

duction of some inhibitory substance formed during the composting process. The pH of the older material, while slightly higher than the pH of pile 5, was still below 8 and was, therefore, not directly the cause of reduction in yield.

It is not possible, from these results, to set an exact limit of time for composting either synthetic or natural manure to be used for

Table 18.—Varying the time of composting. Yield in pounds of mushrooms per ton dry straw.

	PILE 1	PILE 2	PILE 3	PILE 5	PILE 6	
	170.54	107.11	90.81	177.17	166.92	
	128.33	35.82	45.21	317.15	92.38	
	92.31	38.01	75.01	307.58	271.24	
	22.28	27.92	99.85	369.42	280.40	
	74.66	1.75	74.12	282.25	293.96	
Sum of 5 plots	488.12	210.61	385.00	1453.57	1104.90	3642.2
Mean per pile	97.62	42.12	77.00	290.71	220.98	

ANALYSIS OF VARIANCE:

Source of Variation	Degree Freedom	Sum of Sq.	Mean Sq.	F Value
Total square	24	293,602.09		
Between piles	4	222,277.66	55,569.41	15.58
Within piles	20	71,324.43	3,566.22	

Standard deviation: 59.72
Stand. err. of dif. between pr. of pile means: 37.77
Appr. least sig. dif. between pr. of pile means: 78.79

mushroom culture. The rate of decomposition is neither constant nor very controllable. The temperature inside and outside the pile, the moisture content of the compost and the size of the pile exert great influence on this process. Undoubtedly the types of micro-organisms present are also important. Two piles side by side, as were piles 5 and 6 in this experiment, may compost at such different rates that one may be ready to use a week or more before the other. Unless the piles can be maintained in a controlled environment, the grower must still depend on his inexact but practical knowledge of the conditions of a pile which make it favorable for mushroom growing.

From a practical standpoint however, the composting process should be limited to the minimum time necessary to produce a favorable medium for the culture of mushrooms. Composting continued beyond that minimum merely destroys organic material usable by the mushroom without serving any useful purpose. Growers should make tests with small portions of their piles of either synthetic or horse manure to see whether they are composting longer than is necessary. Only by keeping the composting time to a minimum can the grower expect to recover a maximum return per unit of manure bought.

GENERAL CONSIDERATIONS

These experiments indicate that a satisfactory synthetic compost for mushroom culture may be made by using wheat straw, wheat and urea as the basic ingredients. Neither wheat nor urea may be omitted from the compost without materially decreasing the yield of mushrooms.

The finished compost is similar in texture and odor to composted horse manure but differs principally in its greater bulk per unit weight. Consequently, a thicker layer is needed in the beds to give a weight of organic matter equal to that of horse manure. Because of its looser structure, the synthetic compost is more subject to drying both in the pile and in the bed.

This lack of compactness has the advantage of allowing better aeration of the compost. The compost can, therefore, have a higher moisture content than horse manure without interfering with mycelial development of the mushrooms. By chopping the straw in a hay chopper or ensilage cutter before starting the compost, the density of the finished material will approach that of horse manure. This is a relatively inexpensive procedure and aids materially in breaking up the lumps in baled straw.

The rate of decomposition during composting depends, first of all, on the amount of urea and grain added. Table 6 shows that the loss of organic matter during the composting period increases with the amount of wheat used. The same relation holds with urea until 32 pounds per ton of straw are added, table 10. Beyond that point the trend is reversed, probably because of the inhibiting effect of the high ammonia content resulting from rapid decomposition of the urea.

The other factors determining the rate of decomposition are moisture and compactness of the pile. Most growers using synthetic compost fail to realize their importance. Before decomposition can start the straw must be nearly saturated with water. The water should be added and the wet straw left in a pile a day or two before the urea is mixed with it. During both of these manipulations, the straw should be packed by tramping as the pile is being built. The resilience of the raw straw prevents adequate packing by tramping after the turning is complete. If the pile is wet and packed sufficiently, it will begin to heat within a day or two after the urea is added.

The grain may be added with the urea or a few days later. When whole grain is used, the latter time is better since the germ will be killed by the heat before it has time to sprout.

The number of turnings and the total time of composting depends entirely on the rate of decomposition. Our results cast some doubt on the value of extensive decomposition. Satisfactory crops

may be grown on straw that is scarcely decomposed provided it is chopped fine enough to pack quite densely into the beds.

No chemical analyses are reported here. Except for the pH we have yet to find a chemical relation between the substances present in the finished compost which can be regarded as essential to the growth of the mushrooms. The limit of alkalinity which the mushroom apparently can tolerate in the compost (not in the casing soil) is about pH 8.0. If the compost has a higher pH than this the growth is usually very slow. The alkalinity may be a result of a high concentration of ammonia or of amines (ammonia-like compounds). If ammonia is the cause it usually will be driven off in the final heating of the compost after the beds are filled. If amines are the cause they are not so readily volatilized and may remain to impede the later development of the mushrooms. The factors determining whether ammonia or amines are to be produced during the composting are not yet known, but the anaerobic decomposition occurring in very wet piles is undoubtedly the principal cause of amine formation.

In general, the synthetic compost had a pH much below 8.0 after the filled beds were heated. In no case has there been evidence that too great alkalinity of the synthetic compost impeded development of the mushrooms. The same cannot be said for horse manure.

Any one of the three ingredients used in making the synthetic compost may be added to the available horse manure to compensate for a deficiency, although grain should be added only when it is known that the horses have been fed a ration deficient in concentrates. Strawy manure from race tracks and riding stables may be fortified with either urea or grain or both. Manure from stables where little straw bedding is used may be diluted with copious quantities of straw without decreasing the yield.

The grower should not make extensive trials of synthetic compost without first working with small lots until he has familiarized himself with the details and assured himself of its possibilities under his conditions. Neither should he condemn it because of an initial failure. Many of the practices the grower has found essential to successful mushroom culture on horse manure must be modified if he is to have similar success with synthetic compost.

FORMULA FOR SYNTHETIC COMPOST

Following is a summary of a formula that the grower may use in trying synthetic compost. This is by no means the last word on the subject. Its further development will require both the experiences of growers and experimentation in the laboratory.

The objective is to compost the materials rapidly and at a high temperature so that they will reach the best condition for mush-

room growing in the shortest possible time. To bring about rapid decomposition and attain a high temperature, the pile must be wet and compact. The compost should be piled in narrow ricks 5 feet wide. Larger ricks hinder aeration and retard decomposition. The finished compost will be somewhat longer than manure unless the straw is chopped, but should have about the same odor and texture.

One ton of straw will fill approximately 400 square feet of bed after composting.

Piling the straw.—One man should spread the straw while another waters and tramps each forkful as it is distributed. The dry straw must not accumulate to a depth of more than 3 inches or dry spots surely will result. The man spreading must go slowly enough so that the man watering can do a thorough job. This work must be done slowly. The rate will depend on the water supply. If a little water runs through no harm will be done. The finished piles should be 4 to 5 feet high and solidly packed throughout.

First turning.—Four days after piling, make the first turning. Add urea at the rate of 28 pounds per ton of dry straw. It is best applied as a solution of 1 pound per gallon of water.

As each forkful of straw is distributed over the new pile, it should receive a sprinkle of the urea solution from a sprinkling pot and should then be watered and tramped, but *water must not be added in excess* as any water that runs out of the pile will leach away the urea and weaken the compost.

Second turning.—After 4 more days, turn the second time and add wheat at the rate of not more than 400 pounds per ton of dry straw. The wheat should be shelled and wet but not allowed to sprout. Soak it not more than over night either in a trench beside the pile or in bags that can be dipped in a tank, allowing 1 bushel per 100-pound bag. As each forkful of compost is distributed over the new pile, wheat should be thrown over it. Water can be added to keep the pile wet, but *no water should run out at the bottom.* Do not tramp the pile while it is being made up. After the pile is finished it should be firmed down by walking over the top. Keep the wheat in a foot from the edge of the pile to prevent sprouting in the cold exterior. Distribute the wheat evenly.

Third turning.—Turn like manure after adding water as in the latter stages of a manure compost. Do not tramp or walk over the pile.

Filling.—Four days to a week later, when the compost has reached peak heat, fill the beds 7 inches deep and pack quite firmly. Keep the house hot long enough to kill the insects without "fire fanging" the compost too much. Spawn when the temperature drops to 75 to 80 degrees.

SUMMARY

A better comparison of the value of composts for mushroom growing is obtained by expressing yields as pounds of mushrooms produced per ton of manure or of straw used than as pounds of mushrooms produced per square foot of bed.

The droppings in horse manure are not essential to the growth of mushrooms since there was no difference in total yield whether droppings alone or bedding straw alone was used as a basis for compost.

A synthetic compost composed of wheat straw, urea and wheat produced 444 pounds of mushrooms per ton of straw, or nearly as much as horse manure.

The addition of wheat to synthetic compost resulted in more rapid decomposition than when no wheat was present. The piles with wheat added all produced more mushrooms than the one without.

The rate of decomposition of synthetic compost increases as the amount of urea is increased until 32 pounds are present per ton of straw. When more urea than this is added, the rate of decomposition decreases. The most satisfactory compost contained the optimum amount of urea for decomposition.

The yield of mushrooms from synthetic compost per ton of straw and also per square foot of bed decreases as the amount of decomposition increases. The loss in organic matter during composting is the principal cause of this decrease in yield.

A synthetic compost containing wheat straw, urea and wheat may be used for growing mushrooms commercially. A suggested procedure for making such a compost is outlined.

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